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HIGH-SPEED TURNING AND MILLING IN THE AUTOMOBILE INDUSTRY

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This article describes high-speed turning and milling of steel parts at the Gor'kiy Auto Plant imeni Molotov. Cutting tools used are primarily of titanium, tungsten, or cobalt hard alloys.

High-Speed Turning

In some instances, cutters made of hard alloys have been employed in the machine shops of the Gor'kiy Automobile Plant since 1935 - 1936 in single-tool and multiple-tool machines for machining steel parts. Examples of this are the finishing of a divided axle housing with respect to external diameter, finishing of the drive gear of the rear axle, and roughing and finishing the driven gear of the rear axle. The schedule for machining these parts is given in Table 1, appended.

Replacing alloy RE8 with alloy alpha-21 has not met with success because of the mass chipping of the cutting tools. It has become evident that these operations of grinding steel parts with hard-alloy tools were planned in far from the best way; the cutting speeds are relatively low and the geometry of the tools is imperfect.

Cutting-Tool Metals and Geometry

Special experiments were conducted in the plant's metal-cutting laboratory for the selection of hard alloys and the geometry of the cutting edge for various tools. The work was performed by technologists Putov and Ryazanov under the direction of Candidate of Technical Sciences Fel'dshteyn. Three alloys were tested, VK8, T5K10, and T15K6, and three types of tool geometry. The results of testing these under shock and shockless load are shown in Table 2, appended. Conclusions were:

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1. It is not advisable to employ tungsten and cobalt alloy VK8 in either rouguing or finishing. Titanium alloys should be employed for high-speed turning of steel.

2. The alloy T15K6 is superior to the alloy T5K10 in cutting qualities, but is inferior in brittleness.

3. Of the three tool geometries tested under shock and shockless load, the second proved to be the best (double front edge with a positive cutting angle at the face). It also required less cutting pressure than the third one.

4. The comparatively large clearance angle (14 degrees) did not cause chipping of the blade even in roughing steel.

Introduction of High Speed Turning

The first experiment in high-speed turning of steel parts was performed on the MT-30 multitool machine in machining the arm of the driving gear shaft of the GAZ-AA Automobile (40X improved steel), hardness H_B equal 269 - 302 [H_B -- Brinell hardness]. The shape of the part is determined by the two different sections to be machined: (a) the part's cylindrical portion, which is machined by continuous cutting with a dead load, and (b) the radius of the sector (sektor), the machining of which is accompanied by severe shocks. The tools employed had a double front edge: gamma equals 15 degrees, $gamma_1$ equals 3 degrees, the face f equals 0.3 millimeters.

The number of revolutions of the MT-30 machine was increased by replacing the motor with another which had a capacity of 5.6 kilowatts and a greater number of revolutions, and by installing new pulleys.

After the tests had been performed the machine was set as follows: t equals 2 millimeters; s equals 0.2 millimeters per revolution; n equals 460 revolutions per minute. This gives a cutting speed of 110 meters per minute when machining the radius, 55 meters per minute when machining the shaft, and 35 meters per minute when machining the under cut. When working with high-speed cutting tools the number of revolutions of the spindle was n equals 120 per minute.

However, this had to be stopped, because the quantity of shaving interfered with the work. The number of revolutions of the spindle was lowered to n equals 230 per minute. The tools machining the surfaces of the shaft and the under cut were left at high-speed; the tool machining the sector was of T5K10 hard alloy. Its geometry: alpha equals 12 degrees, gamma equals 15 degrees; $gamma_1$ equals 5 degrees; f equals 0.3 millimeters; lambda equals plus 10 degrees; phi equals 60 degrees; phi_1 equals 15 degrees; r equals 1.5 millimeters. As a result, productivity was doubled in this operation.

Of great interest is the high-speed turning (roughing and finishing) of the tow hook of the GAZ-51 trucks on the Model 116 multitool semiautomatic lathe made by the Plant imeni Ordzhonikidze. The blank is a forging of 45 steel with a hardness of H_B equals 156 - 207. The total length of the blank is 430 millimeters, and the maximum diameter is 45 millimeters. The average allowance varies from 3 to 4.5 millimeters on each side; however, because of play the maximum allowance reaches, as a rule, 6 - 7 millimeters. Because the hook itself is not symmetrically placed relative to the center of the part, there is a disbalance (disbalans) of up to one kilogram, the total weight of the billet being 7 kilograms.

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The machining of the part was to be done simultaneously with seven tools, of which one was grooved. The roughing tools were given the geometry: double front edge gamma equals 20 degrees, gamma$_1$ equals 5 degrees, f equals 0.5 millimeters; lambda equals plus 5 degrees, alpha equals 12 degrees.

To eliminate chipping of the blades because of increased longitudinal feed at the moment of cutting, and because of heavy vibration in the machine, the cutter forms were changed, as a result of which the finally established speeds of cutting and feed were equal to: v equals 52 meters per minute (with n equals 330 revolutions per minute); s longitudinal equals 0.22 millimeters per revolution in incision and 0.35 millimeters per revolution in subsequent work, and s transverse equals 0.17 millimeters per revolution. With this the incision was made lightly, breakdowns of the tools was stopped, but the heavy vibration and chipping of the tools continued.

To reduce vibration the motor was removed from the machine and set up on a separate sturdy plate; a sheet of rubber 6 - 8 millimeters thick was placed under the base plate, and a counterweight was installed on the catch plate to correct the dynamic disbalance.

The vibration of the machine was somewhat lessened, but not eliminated. The vibration was finally eliminated after the radius of curvature of the cutting point of the tools had been increased, some to 2 - 3 millimeters, and others to 1 - 1.5 millimeters. Many other experiments and observations both in the laboratory and in the shop show that it is possible to eliminate vibrations safely and completely in this way.

Elimination of vibrations of the tools operating from the rear support was worked out by proper choice of the geometric parameters of the tools. Two different sets of measurements with which vibrations did not arise and in which the shaving came off easily and curled freely were found: first set -- gamma equals 0; alpha equals 15 degrees; second set -- gamma equals 10 degrees; alpha equals 5 degrees (with tool sharp).

Other tests for durability were performed with the front and rear supports working simultaneously. Tools made of the alloys T5K6, T5K10, and KM were tried out. It was established that with v equals 52 meters per minute the roughing tools made of alloy KM were less durable than tools of the alloy T5K10. There was considerable wear on the tools made of alloy KM after 15 - 20 parts had been machined. On the same tools made of the alloys T5K6 and T5K10 there was considerably less wear, but on the other hand, in machining parts with large play, partial chipping of the T5K6 and T5K10 blades were observed, which could not be said of alloy KM. The tests dictated the choice of alloy T5K10. The geometry of the undercutting tool is: gamma equals 10 degrees, alpha equals 5 degrees. The hard alloy used is VK8. The capacity of the motor installed in the machine tool is 10 kilowatts.

Productivity in high-speed turning with hard-alloy tools is 250 percent of productivity with tools of high-speed steel.

High-speed turning of the main shaft in the gear box has been set up on the same Model 116 multitool semiautomatic lathe.

The part is made of 40X select (selekt) steel, of hardness H_B equals 200. The blank of the part, with a total length of about 250 millimeters, and a diameter of 42 millimeters, is simultaneously machined by six tools, tool No 6 of which is a shaper tool. The allowances are: 2 millimeters for tools No 1 and No 2, 1.8 millimeters for No 3, 1.7 millimeters for No 4, and one millimeter for No 5.

By replacing the pulleys, the number of revolutions of the spindle of the machine was increased to 400, which is the equivalent of a cutting speed of v equals 55 meters per minute.

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The geometry of the roughing tools: gamma equals 20 degrees, $gamma_1$ equals 5 degrees, f equals 0.3 millimeters, lambda equals plus 5 degrees, alpha equals 12 degrees, and r equals 1.5 millimeters. The alloy used is T5K10.

The machining of the part was accompanied by the formation of a large amount of shaving coming out in the form of a straight ribbon and constituting a great danger to the operator. The shaving was curled by grinding a step on the face of the tool. This step was ground 5 millimeters wide and 1.5 millimeters deep parallel to the main cutting edge. This step made sure, for the most part, that the shaving curled.

The shaft of the steering arm of the GAZ-51 truck, in contrast to the same part of the GAZ-AA is machined on the TM-44 multitool semiautomatic lathe. The part is made of 30X select steel, improved to a hardness of H_B equals 269-321. Four tools machine the part simultaneously. Tool No 4 is the undercutting tool. All the tools are fitted with blades of alloy T5K10.

The geometry of the roughing tools is: gamma equals 20 degrees, $gamma_1$ equals 5 degrees, f equals 0.3 millimeters, lambda equals plus 5 degrees, and alpha equals 12 degrees. The allowance is t equals 1 millimeter. The cutting rate is: s equals 0.24 millimeters per revolution, n equals 500 revolutions per minute, which is equivalent to a cutting speed of v equals 50 meters per minute on the spindle and v equals 114 meters per minute in the sector (na sektoro). The machine has a 10-kilowatt motor.

Machining of the end of the Cardan shaft of the GAZ-51 has also been set up on the T-44 multitool semiautomatic lathe. The part, which is made out of 40 steel is simultaneously machined by four tools, of which tool No 4 is the shaper tool. The established schedule is: s equals 0.34 millimeters per revolution, t equals 2 millimeters, v equals 130 meters per minute (the maximum for the undercutting tool), and v equals 65 meters per minute (for the roughing tools). The geometry of the tools: for the roughing tool gamma equals 20 degrees, $gamma_1$ equals 5 degrees, f equals 0.3 millimeters, lambda equals plus 5 degrees, alpha equals 12 degrees, phi equals 70 degrees, and phi_1 equals 20 degrees. The alloy used is T5K10; and the capacity of the machine's motor is 10 kilowatts.

In 1946-1947, the alloy VK8, formerly used to make tools for machining the crown wheel of the rear axle, was replaced by the alloy T5K10. It was thought that this substitution would make it possible to increase the maximum cutting speed from 49 to 80-120 meters per minute. However, it turned out that such an increase of cutting speed in this case would be impossible since the showing covered the part and the tool, resulting in accidents.

At present, the semiautomatic boring and turning lathe is used for roughing and finishing the blank of the gear of the divided rear axle, and for undercutting the face of the steering knuckle of the GAZ-51. In both cases the tools are fitted with the hard alloy T5K10, and the speeds of cutting are set at about 50 meters per minute.

Hard-alloy roughing tools are employed on automatic lathes in machining the bolt and shaft of the hand-brake lever.

The tangential roughing tool for turning the bolt's shaft, which is made on a four-spindle automatic machine from a cube, has a double front edge: gamma equals 16 degrees, $gamma_1$ equals -4 degrees with a clearance angle of alpha equals 8 degrees. The size of the face on the front edge is f equals 0.1-0.3 millimeters. The blade is made of the hard alloy T15K6. The allowance is t equals 3-4 millimeters; the feed is s equals 0.06 millimeters per revolution, the cutting speed is v equals 41 meters per minute. Before, when this tool was made of highspeed steel, the cutting speed was v equals 26 meters per minute.

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The radial roughing tool for turning the two diameters of the shaft has a positive cutting angle of gamma equals 10 degrees and a clearance angle of alpha equals 6 degrees and is equipped with the hard alloy T15K6. The surplus being removed is 1.5 - 2.5 millimeters, the feed is s equals 0.04 millimeters per revolution, the speed of cutting is v equals 66 meters per minute. When these tools were made of high-speed steel, the cutting speed was v equals 25 meters per minute.

For a long time diamond boring of steel was generally considered impossible. In the Automobile Plant imeni Molotov the opening under the bearing in the crankshaft of the motor 12 (45 steel, H_B equals 179 - 228) is now being successfully diamond-bored. The cutter is reinforced with the hard alloy T30K4. The operating geometry is: gamma equals 5 degrees, lambda equals plus 5 degrees, phi equals 5 degrees, alpha equals 6 degrees, and r equals 0.4 millimeters. The cutting schedule: t equals 0.15 millimeters, s equals 0.06 millimeters per revolution and v equals 145 meters per minute. There is ample cooling by emulsion.

Machining under the above conditions has indicated the following: (a) The durability of the tool is 3.5 hours, which is the equivalent of boring 1,500 crankshafts; (b) adjusting for size has to be done every 20 minutes on the average, which is equivalent to boring 150 crankshafts; (c) the Soviet alloy T30K4 in this operation is almost twice as durable as the American alloy Carboloy 831; and (d) the productivity of diamond boring is almost three times the productivity of grinding.

Engineer Brakhman, who introduced this operation, also performed experiments with the diamond boring of large end of the connecting rod of the motor 12 (45G-2 select steel, H_B equals 228 - 269).

In contrast to the preceding operation, the tool in this case operated under shock, which was caused by the presence of oil grooves.

For operation with a dynamic load Engineer Brakhman came to the following conclusions:

1. The hard alloy T30K4 is suitable for the diamond boring of steel in noncontinuous cutting.

2. The tool must have the operating geometry: gamma equals -3 degrees to -7 degrees, lambda equals plus 30 degrees to plus 35 degrees, phi equals 40 divided by 45 degrees, phi_1 equals 12 divided by 14 degrees, r equals 0, and alpha equals 7 divided by 8 degrees.

3. The finish of the surface after diamond boring is equal to 25 - 40 mu.

4. With a cutting schedule t equals 0.2 millimeters, s equals 0.06 millimeters per revolution, v equals 150 meters per minute, the durability of the tool is 70 - 75 minutes, which is equivalent to boring 115 - 125 shafts.

5. The machine tool for diamond boring must be designed so that the cutter may be accurately and quickly adjusted for size, since loss of size (in work of first- and second-class accuracy) occurs more frequently than conspicuous dulling of the tool.

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High-Speed Milling

Fewer difficulties are met in adjusting horizontal milling machines for high-speed milling with face cutters than in other cases.

A typical operation of this kind is the milling of the faces of shafts. When the machine is in a normal state and the milling cutters are sufficiently sharp, this operation takes place without any complications. The T6G-82 machine tool is used for milling the faces of the crankshaft of a tractor engine in the Gor'kiy Automobile Plant. It is made of 20X steel. The cutter was equipped with the alloy T15K6. The dimensions of the cutter and its efficiency are as follows: diameter of the cutter is 150 millimeters, number of teeth is 8, transverse cutting angle is 10 degrees, longitudinal cutting angle is 10 degrees, cutting speed is 200 meters per minute, feed per tooth is 0.04 millimeters, the feed is 135 meters per minute, machining time is 0.8 minutes, and durability is 25 parts.

Despite the fact that in this case the feed was too low for the hard-alloy cutter, and that the cutting speed was somewhat high, the machining time of the operation was one fourth of what it had been and the durability of the tool 1.65 times as great.

By changing the design of the cutter, machining time was cut to one fourth its previous time, while the tool lasted 2.5 times as long. High-speed milling was employed for milling the faces of the driving gear of the GAZ-AA rear axle on the vertical milling machine with circular feed. The material being machined is 20X steel with a hardness H_B equals 207, and an established cutting speed of v equals 207 meters per minute, and an instantaneous feed of 462 meters per minute. High-speed cutters worked on this operation with a cutting speed of 20 meters per minute, and an instantaneous feed of 110 meters per minute.

The cutting speed is increased by changing the gears in the gear case of the machine and putting new pulleys on the shaft of the motor. Wiht this speed, the durability of the cutter is 240-270 minutes.

High-speed milling on horizontal and vertical milling machines has also been much used in the tool and die shop and in other auxiliary shops of the Gor'kiy Automobile Plant.

In conclusion we shall describe an experiment in the conversion of the planing machine for long work into a milling machine by installing a high-powered engine and a specially designed head on the crossarm. This change was proposed by V. Ya. Frolov.

An adequately rigid planing machine for long work was selected for conversion. The cutter holders were removed from the crossarm of this machine and replaced by a special head with a 40-kilowatt electric motor having a speed of 1,420 revolutions per minute.

The ranges of speeds when machining with milling heads with diameters of 150 - 250 millimeters were from 54.6 to 473 meters per minute.

In the head, the idler shafts operate on ball bearings and the spindle on conical roller bearings.

The rapid raising and lowering of the cutter is done by raising and lowering the crossarm of the machine. Setting the depth to be traversed is accomplished by raising and lowering the housing in which the spindle bearings are located.

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The housing is raised and lowered as follows: A cut is made on the [illegible] of the housing and a worm wheel with a cut in its bore is screwed onto [illegible]. The wormwheel is attached to the body of the head in such a way that there [illegible] possibility of axial displacement; the worm wheel is rotated by a worm, [illegible] hand rotated by the operator. Thus, by rotating the worm the operator sets [illegible] height of the face cutter.

A flywheel with a diameter of 400 millimeters and a weight of 55 kilograms was placed at the upper end of the spindle to make the face cutter work more evenly.

Since the longitudinal speed of the table of the planing machine was too great for milling feeds, an additional two-step reducer was placed in the feed circuit. After this conversion the machine has the following feeds: 150, 200, 290, 310, 400, 490, 620, and 780 millimeters per minute.

The modified machine can perform high-speed milling of steel and pig iron.

At all the aforementioned cutting speeds the machine operates smoothly and no strain or vibration are observed, despite the fact that the work is frequently performed with very deep cuts and uneven allowance with respect to the skin of the cast blank.

A milling cutter with eight detachable teeth of alloy T15K6 is used. The diameter of the cutter is 200 millimeters, the cutting angles (radial and axial) are 10 degrees, and the clearance angle is plus 12 degrees.

The maximum allowance removed by the cutter is 10 millimeters, the cutting speed is v equals 100 - 110 meters per minute, and the feed per tooth is s_t equals 0.13 millimeters.

The productivity in high-speed milling of die cubes (kubik shtampov) is four times the productivity of planing.

Table 1

Order	Operation	Kind of Steel and Brinell Hardness	Cutting Schedule v	s	t	Required Sharpening phi	phi_1	gamma	alpha	r	Alloy	Durability (in min)	Machine
1	Turning after removal of skin of divided axle	40 improved steel H_B= 293-330	12.8	0.38	1.0	75°	30°	7°	6°	2.0	[illegible]	[illegible]	
2	Finishing taper of driving gear of rear axle	6120 steel H_B= 156-207	58.0	0.58	1.0	75°	35°	10°	6°	1-1.5	RE8	800-900	Multi-tool
3	Roughing driven gear of rear axle	40X H_B= 160-210	49.6	0.3	2.5	70°	30°	5°	5°	3.0	RE8	80-100	Multi-spindle boring and turning lathe
4	Finishing this gear	H_B= 160-210	49.0	0.34	0.75	90°	8°	5°	5°	1.0	RE8	250-500	Semi-automatic lathe

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Table 2.

Type of Sharpening	Geometry of Sharpening	phi / phi_1	r (mm)	Cutting Schedule				Dulling [illegible] After 30 - [illegible]			
				Steel	v (m/min)	s (mm/rev)	t (mm)	VK8	T[illegible]K10	[illegible]	
I		$\frac{60}{10}$	1.0	38X	65	0.3	3.0	1.60	0.45	0.4	[illegible]
		$\frac{60}{10}$	1.0	38X	100	0.3	3.0	Burned	0.4	0.2	[illegible] load
II		$\frac{60}{10}$	1.0	38X	65	0.3	3.0	0.9	0.35	0.25	Shock load
		$\frac{60}{10}$	1.0	38X	100	0.3	3.0	Burned	0.35	0.18	Uniform load
III		$\frac{60}{10}$	1.0	38X	65	0.3	3.0	1.3	1.1	1.1	Uniform load
		$\frac{60}{10}$	1.0	38X	100	0.3	3.0	Burned	0.35	0.18	Uniform load

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